A White Paper:

IAFIS IMAGE QUALITY SPECIFICATIONS FOR SINGLE FINGER CAPTURE DEVICES

1.0 SCOPE, PURPOSE AND BASIC ATTRIBUTES

These specifications apply to fingerprint capture devices which scan and capture at least a single fingerprint in digital, softcopy form, for such primary applications as the United States government's Personal Identity Verification program [PIV]. These specifications provide criteria for insuring that the image quality of such devices is sufficient for the intended applications; a primary application is to support subject authentication via one-to-one fingerprint matching.

The image quality requirements covered in the following sections have associated test procedures which are described in detail in [Test Procedures]. These test procedures will be used by the FBI principally for certification of these devices; they may also be used in acceptance testing, and in performance capability demonstrations, as an indication of capability-to-perform.

The fingerprint capture device must be capable of producing images which exhibit good geometric fidelity, sharpness, detail rendition, gray-level uniformity, and gray-level dynamic range, with low noise characteristics. The images must be true representations of the input fingerprints, without creating any significant artifacts, anomalies, false detail, or cosmetic image restoration effects.

Table G-1 gives basic requirements of the device, which include minimum capture size, minimum resolution and scale, and output image type.

Table G-1. Basic Requirements

Parameter	Requirement
Capture Size	≥ 12.8 mm wide by ≥ 16.5 mm high
True Optical or Native Resolution	≥ 500 ppi in sensor detector row and column directions
Resolution Scale	490 to 510 ppi in sensor detector row and column directions
Image Type	Capability to output monochrome image at 8 bits per pixel, 256 gray-levels (prior to any compression)

mm = millimeters
ppi = pixels per inch
≥ greater than or equal to

Due to the variety of the physical principles of operation that could be utilized to capture the fingerprint, e.g., optical, capacitive, thermal, acoustic, holographic, radio frequency, various contactless and swiping technologies, etc., the test methods and targets given in this Appendix may not all apply to a specific device. In such cases, the vendor is encouraged to recommend alternate testing methods and/or targets, always keeping in mind that the goal is to arrive at targets and test methods that enable verification of the requirements. [Targets need not be commercial off-the-shelf items; it may be necessary for the vendor to have targets fabricated on special substrates, or have 3-dimensional targets fabricated.]

The device shall be tested to meet the requirements in its normal-operating-mode, with the following exceptions:

1) For the tests involving targets, the device shall be setup in a linear or near-linear input/output mode, i.e., output gray-level is linear/near-linear with respect to input signal.

2) If the device has a strong anti-spoofing feature, of a type whereby only live fingerprints will produce an image, then this feature needs to be switched-off or bypassed in the target test mode of operation.

3) If the device's normal output is not a monochrome gray scale image, e.g., it is a binary image, minutia feature set, color image, etc., then the monochrome gray scale image needs to be accessed and output in the test mode of operation.

4) Other normal-operating-mode features of the device similar to (2) and (3) may need to be disengaged.

2.1 GEOMETRIC ACCURACY

Requirement #1 (across-bar)
A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The absolute value of the difference between the actual distance across parallel target bars, and the corresponding distance measured in the image, shall not exceed the following values, for at least 99% of the tested cases and in each of the two orthogonal directions.

$$D \leq 0.0011, \quad \text{for } 0.00 < X \leq 0.07$$

$$D \leq 0.015X, \quad \text{for } 0.07 \leq X \leq 1.50$$

where:

$D = |Y-X|$
X = actual target distance
Y = measured image distance
D, X, Y are in inches

Requirement #2 (along-bar):
A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The maximum difference between the horizontal direction locations (for vertical bar) or vertical direction locations (for horizontal bar), of any two points separated by up to 1.5 inches along a single bar's length, shall be less than 0.022 inches for at least 99% of the tested cases in each direction.

Background:
The phrase: *multiple, parallel bar target* refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern at 1.0 cy/mm, with high contrast ratio and fine edge definition. This target can also be used to verify compliance with the device's resolution scale requirement given in Table G-1.

Across-bar geometric accuracy is measured across the imaged Ronchi target bars, which that cover the total image capture area. The requirement corresponds to a positional accuracy of ± 1.5% for distances between 0.07 and 1.5 inches, and a constant ± 0.0011 inches (1/2 pixel) for distances less than or equal to 0.07 inches.

Along-bar geometric accuracy is measured along the length of an individual Ronchi bar in the image. For a given horizontal bar, for example, the maximum difference between bar center locations (in vertical direction), determined from bar locations measured at multiple points along bar's length, is compared to the maximum allowable difference requirement (analogously for

vertical bar). This requirement is to ensure that pincushion, barrel, or other types of distortion are not too large, over the area of a single fingerprint.

2.2 SPATIAL FREQUENCY RESPONSE

Requirements:
The spatial frequency response shall normally be measured using a bi-tonal, high contrast bar target, which results in the device's Contrast Transfer Function (CTF), or by using a continuous-tone sine wave target, which results in the device's Modulation Transfer Function (MTF)[1]. The CTF or MTF shall meet or exceed the minimum modulation values defined in Table G-2, in both the detector row and detector column directions, and over any region of the total capture area. CTF specification minimum values for frequencies not listed in Table G-1 are defined in Equation G-1.

None of the CTF modulation values shall exceed 1.15, and the bar target image shall not exhibit any significant amount of aliasing.

Table G-2. CTF and MTF Requirements at Nominal Test Frequencies

Frequency (f) in cy/mm	Minimum CTF Modulation when using Bar Target	Minimum MTF Modulation when using Sine Wave Target
1.0	0.920	0.870
2.0	0.822	0.736
3.0	0.720	0.616
4.0	0.620	0.510
5.0	0.526	0.420
6.0	0.440	0.344
7.0	0.362	0.280
8.0	0.293	0.227
9.0	0.232	0.178
10.0	0.174	0.134

Equation G-1:

[1] If the particular device cannot use a bar target or sine wave target, i.e., a useable/measureable image cannot be produced with one of these targets, then use of an edge target would be considered. Assessment of the MTF from an edge target will basically follow [ISO 12233-2000], tailored for the application at hand.

$$CTF = -5.71711E-05 * f^4 + 1.43781E-03 * f^3 - 8.94631E-03 * f^2 - 8.05399E-02 * f + 1.00838$$

where f = 1.0 to 10.0 cy/mm for 500 ppi device

Background:
It is not required that the bar target contain the exact frequencies listed in Table G-2; however, the target does need to cover the listed frequency range, and contain bar patterns close to each of the listed frequencies. Equation G-1 defines the specification CTF minimum values for a bar target having frequencies not listed in Table G-2.

For CTF assessment, the single, representative modulation in each imaged bar frequency pattern is determined from the sample modulation values collected from within that pattern. The sample modulation values are computed from the maximum and minimum levels corresponding to the 'peak' and adjacent 'valley' in each bar+space period (cycle). The CTF modulations are determined directly in image space, normalized by the image modulation at zero frequency. The device CTF at each frequency is then defined as:

CTF = peak image modulation / (zero frequency image modulation)

The bar target must contain at least 10 parallel bars at each of the higher spatial frequencies (~50% Nyquist to Nyquist frequency), which helps to ensure capture of optimum phasing between the target and the device's sensor, and aids investigation of potential aliasing. The bar target must also contain a very low frequency component, i.e., a large square, single bar, or series of bars whose effective frequency is no greater than 3 % of the device's final output resolution. This low frequency component is used in normalizing the CTF, it must have the same density as the other target bars. The bar target can be fabricated on any substrate suitable for the given device, as either a reflective or transmissive, two-dimensional or three-dimensional target.

The upper CTF and MTF limit of 1.15 modulation is to discourage image processing that produces excessive edge sharpening, which can add false detail to an image.

Aliasing on sine wave images or bar images can be investigated by quantitative analysis and from visual observation of the softcopy-displayed image. It is recognized and accepted that some amount of aliasing-due-to-decimation is often unavoidable at the higher frequencies, but aliasing-due-to-upscaling should not occur at any frequency; the latter is a sign that the true optical resolution of the device does not meet the minimum requirement of 500 ppi.

[Sine wave MTF assessment procedures are given in section 2.3.3 of Appendix F.]

2.3 GRAY-LEVEL UNIFORMITY AND SIGNAL-TO-NOISE RATIO (SNR)

Requirement #1 - adjacent row, column uniformity:
At least 99% of the average gray-levels between every two adjacent quarter-inch long rows and 99% between every two adjacent quarter-inch long columns, within the capture area, shall not differ by more than 1.5 gray-levels when scanning a uniform low reflectance target, and shall not differ by more than 3.0 gray-levels when scanning a uniform high reflectance target.

Requirement #2 - pixel to pixel uniformity:
For at least 99.0% of all pixels within every independent 0.25 by 0.25 inch area located within the capture area, no individual pixel's gray-level shall vary from the average by more than 22.0 gray-levels, when scanning a uniform high reflectance target, and shall not vary from the average by more than 8.0 gray-levels, when scanning a uniform low reflectance target.

Requirement #3- small area uniformity:
For every two independent 0.25 by 0.25 inch areas located within the capture area, the average gray-levels of the two areas shall not differ by more than 12.0 gray-levels when scanning a uniform high reflectance target, and shall not differ by more than 3.0 gray-levels when scanning a uniform low reflectance target.

Requirement #4 - SNR:
The white signal-to-noise ratio and black signal-to-noise ratio shall each be greater than or equal to 110.0, in all of the test cases within the capture area.

Background:
Any suitable uniform light gray target and dark gray target may be used for measuring requirements 1 to 4, including a pseudo-target. [The pseudo-target concept images the blank capture area with the exposure time turned up or down, producing a uniform light gray or dark gray image, respectively.]

For SNR, the signal is defined as the difference between the average output gray-levels obtained from the light gray and dark gray targets, measuring the average values over independent 0.25 by 0.25 inch windows withinthe capture area. The noise is defined as the standard deviation of the gray-levels in each of these quarter-inch windows. Therefore, for each high reflectance, low reflectance image pair there are two SNR values, one using the high reflectance standard deviation and one using the low reflectance standard deviation.

In order to obtain a true measure of the standard deviation for SNR requirement #4, and for the parameters in requirements #1, #2, #3, the device is set up such that the white average gray-level is at least 4 gray-levels below the device's highest obtainable gray-level and the black average gray-level is at least 4 gray-levels above the device's lowest obtainable gray-level.

2.4 FINGERPRINT IMAGE QUALITY

The fingerprint capture device shall provide fingerprint image quality which is high enough to support the intended applications; a primary application is to support subject authentication via one-to-one fingerprint matching.

The image quality will be assessed with respect to the following requirements, by applying visual and quantitative measurements to test livescans captured on the given device. These test livescans shall consist of:

- a set of 20 fingers, nominally acquired from 10 different subjects and 2 fingers per subject (preferably left/right index finger) and,

- a set of 5 index finger repeat captures from the same hand of a single subject.

All of these test livescans shall be supplied for assessment in 8 bits per pixel, monochrome (grayscale), uncompressed format (and have never been lossy-compressed).

Requirement #1 - Fingerprint Gray Range:
At least 80.0 % of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 150 gray-levels.

Background:
Dynamic range is computed in terms of number of gray-levels present that have signal content, measuring within the fingerprint area and substantially excluding non-uniform background areas.

Requirement #2 - Fingerprint Artifacts and Anomalies:
Artifacts or anomalies detected on the fingerprint images, which are due to the device or image processing, shall not significantly adversely impact supporting the intended applications.

Background:
The fingerprint images will be examined to determine the presence of artifacts or anomalies which are due to the device or image processing; assessment may include measurements to quantify their degree of severity and significance. Image artifacts or anomalies such as the following non-inclusive list may be investigated:

• jitter noise effects
• localized offsets of fingerprint segments
• sensor segmentation / butt joints
• noise streaks, dead pixels
• gray-level saturation
• poor reproduceability

Requirement #3 - Fingerprint Sharpness & Detail Rendition:
The sharpness and detail rendition of the fingerprint images, due to the device or image processing, shall be high enough to support the intended applications.

Background:
Fingerprint sharpness and detail rendition, which is due to the device or image processing, may be investigated by employing suitable, objective image quality metrics, as well as by visual observation of the softcopy-displayed images.

REFERENCES

[ISO 12233-2000] - *Photography--Electronic still-picture cameras--Resolution measurements*, International Organization for Standardization

[PIV] Personal Identity Verification; information available at:
http://csrc.nist.gov/piv-program/

[TestProcedures] - *Test Procedures for Verifying IAFIS Image Quality Requirements for Fingerprint Scanners and Printers*, MITRE Technical Report, MTR-050000016, April 2005, MITRE Corporation, Beford, MA.
Document available at: http://www.mitre.org/tech/mtf
Note: These test procedures were established for Appendix F testing; however, most of the detailed test procedures, discussions, and target descriptions can be used as guidance for Appendix G testing.